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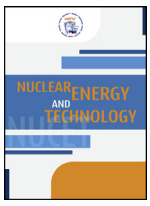

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Application of zonality conceptual model of chronic effects of ionizing radiation for studying the behavior of Sr-90 in terrestrial ecosystems

R.R. Shoshina[a], G.V. Lavrentyeva[a,b,*], B.I. Synzynys[a]

[a] *Obninsk Institute for Nuclear Power Engineering, National Research Nuclear University MEPhI., 1 Studgorodok, Obninsk, Kaluga Region 249040, Russia*
[b] *Kaluga branch, Bauman Moscow State Technical University., 2 Bazhenov str., Kaluga, 248000, Russia*

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Abstract

Behavior of Sr-90 radionuclide in the system of «soil-plants-mollusc shells» was investigated on the example of biotope of regional radioactive waste storage facility. The purpose of the study was to examine the possibility of applying the conceptual model of zonality of chronic effects of ionizing radiation in natural populations in the investigation of behavior of radioactive strontium in terrestrial ecosystems and to identify radioecological zones of biological effects of chronic exposure to ionizing radiation of the mollusc population based on of the bio-geochemical regularities of technogenic migration of Sr-90 within the «soil-plants-mollusc shells» system. The study was conducted on the experimental site which represented the biotope of the regional radioactive waste storage facility. Analysis of samples of soil, plant (Urtica dioica) and terrestrial molluscs was implemented by the method of radiochemical separation followed with measuring the activity of the radionuclide using scintillation spectrometer «BETA-01C». Annual exposures to external beta-radiation received by tissues of molluscs irradiated by Sr-90 and its daughter radionuclide Y-90 contained in the shells were calculated using Levinger and Marinelli formula.

It was discovered that dose rates of irradiation of molluscs *Bradybaena Fruticicola fruticum* are within 0.03–1.60 Gy/year. Structuring of experimental data was implemented based on the obtained data on the specific activity of Sr-90 in the system under study in accordance with model by G.G.Polikarpov. Three ecological zones were identified on the experimental site with regular variation of specific activity of Sr-90 in mollusc shells. In the zone of physiological masking concentration of radionuclide in mollusc shells can be by one order of magnitude and even more higher than in the plant. In the zone of ecological masking and the zone of pronounced environmental effects specific activities of the radionuclide are reduced as compared to its concentration in plants by 8 and 40 times, respectively (no decrease of specific activities of the radionuclide in the plant is regisrered). The implemented studies allow formulating the conclusion on the possibility of adaptation of indicators of Sr-90 migration in terrestrial ecosystems.

Keywords: Sr-90; Terrestrial molluscs *Bradybaena Fruticicola fruticum*; ecological zone; dose rate; soil and plants.

Introduction

Investigation of radiation sensitivity of animals is of interest for evaluation of the process of adaptation of organisms to the conditions of increased radiation background. It is possible with this respect to take into account different indicators including genetic and morphological indicators, populations of species, behavioral activity, etc.

Conceptual model of zonality of chronic effects caused by ionizing radiation can be of interest among the wide spectrum of other models [1,10,14 and 18] developed for identification of response by biota components to the effects of different genesis. Using this model it is possible to implement evaluation forecasting of biota conditions with identification of radio-ecological zones of dose rates of ionizing radiation in nature. Registration of changes taking place in the most sensitive structures and functions of living organisms and their communities constitutes the basis of identification of ecological zones.

* Corresponding author at: Obninsk Institute for Nuclear Power Engineering, National Research Nuclear University MEPhI., 1 Studgorodok, Obninsk, Kaluga Region 249040, Russia.

E-mail addresses: regina.rinatovna.m@mail.ru (R.R. Shoshina), Lavrentyeva_G@list.ru (G.V. Lavrentyeva), ecology@iate.obninsk.ru (B.I. Synzynys).

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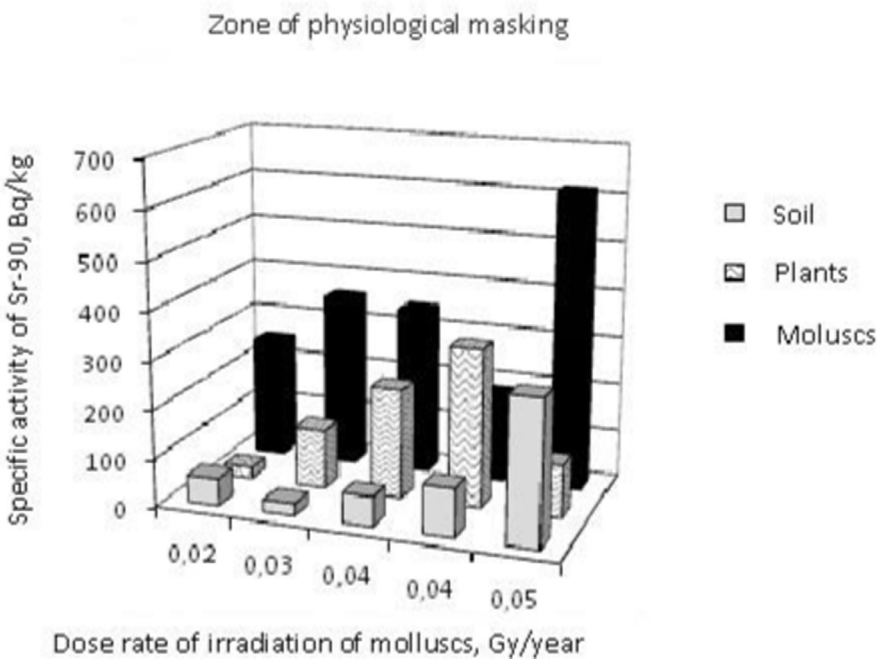

Fig. 1. Variation of specific activity of Sr-90 within the "soil-plants-mollusc shells" system within the physiological masking zone.

Attempt was made in the present study to identify radio-ecological zones of biological effects induced by chronic irradiation by ionizing radiation of populations of terrestrial molluscs *Bradybaena Fruticicola fruticum* on the basis of biological regularities of migration of technogenous Sr-90 within the system "soil-plants-mollusc shells".

Materials and methods

Biotope of regional radioactive waste storage facility placed under the conditions of chronic irradiation as the result of the uncontrolled source of penetration of technogenous radionuclides developed following leakage from one of storage tanks at the facility serves as the experimental site [2,3,11,12]. Radio-ecological environment on the territory of the storage facility is determined by Sr-90 [12,21]. Selection of samples of soil, plant and terrestrial molluscs was implemented on local areas within the experimental site representing interest from the viewpoint of variation of values of dose rates of irradiation of molluscs [16].

Selection of samples of soil was implemented by the "envelope" method from the surface of soil cover underlying plant from the local areas equal to 1 m^2 on which molluscs dwell and from layers (0–5 cm and 20 cm depth).

Selection of samples of plants (stinging nettle *Urtica dioica*) was implemented taking into account specific features of habitation of molluscs on the local areas.

Molluscs were collected in the numbers amounting to not less than 8–10 species. Average age of terrestrial molluscs was determined for more correct calculation of dose rates of irradiation of animals [5]. Method of radiochemical separation with subsequent measurement of activity of the radionuclide using BETA-01S scintillation spectrometer according to standard methodology of determination of Sr-90 concentration by beta-radiation emitted by its daughter radionuclide Y-90 was applied for determination of Sr-90 concentration in the selected samples [7].

Calculation of annual exposures of mollusk tissues from external beta-radiation emitted by Sr-90 and its daughter radionuclide Y-90 contained in the shells was performed using Levinger and Marinelli formulas for cold and warm periods of the year [19].

Results and discussion

Calculation of absorbed dose rates for molluscs taking into account specific activities of radiation emitted by Sr-90, Cs-137, K-40 and Ac-228 demonstrates that the main part of the absorbed dose for molluscs refers to external irradiation shaped by Sr-90 (taking into account the main contribution made by Y-90) for all the investigated local areas [12]. It is known that molluscs can act as indicators of Sr-90 content in the natural environment due to their capability to accumulate the radionuclide in their shells [17,20].

It has to be noted that approaches to the interpretation of data on the concentrations of radionuclides in components of ecosystems are wide enough including bio-geochemical indicators of migration of radionuclides, evolution of morphological indicators, behavioral activity, genetic indicators, etc. Functional dependences of variation of specific activity of Sr-90 within the "soil-plants-mollusc shells" system may be of interest here.

Functional dependences obtained as the result of the experiment were processed and distributed in accordance with conceptual model of zonality of chronic effects of ionizing radiation [8,9,14,15]. In agreement with the model under

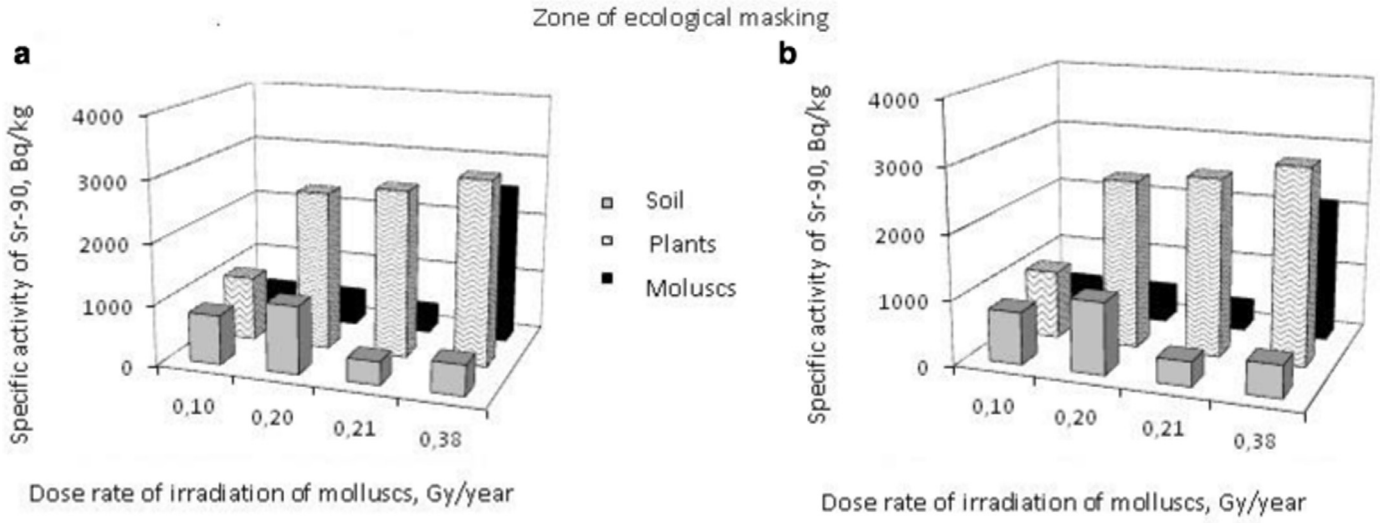

Fig. 2. Variation of specific activity of Sr-90 within the "soil-plants-mollusc shells" system within the ecological masking zone.

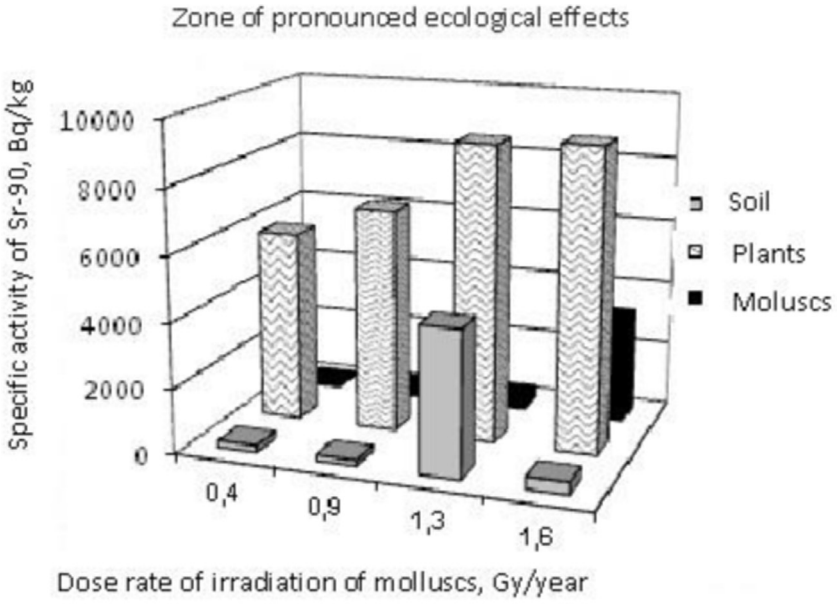

Fig. 3. Variation of specific activity of Sr-90 within the "soil-plants-mollusc shells" system within the zone of pronounced ecological effects.

discussion ecosystem subjected to chronic effects of ionizing radiation are divided into the following five categories of zoning: *zone of uncertainty* (below the lowest level of natural background < 0.00001–0.00004 Gy/year); *zone of radiation welfare* (within the limits of natural background 0.00004–0.005 Gy/year); *zone of physiological masking* (0.005–0.05 Gy/year); *zone of ecological masking* (0.05–0. 4 Gy/year) and *zone of pronounced effects* (> 0.4 Gy/year; this is the zone of dramatic effects for terrestrial animals). The above classification is extended to all levels of organization of living nature taking into consideration changes in the most radiation sensitive structures and functions of living organisms and their communities [14]. Application of the model at the level of animal species taking into consideration the functional dependences of variation of specific activity of Sr-90 within the "soil-plants-mollusc shells" system is examined in the present paper.

Analysis of obtained values of dose rates of irradiation of molluscs within the limits of the investigated experimental site allows making the conclusion that neither of the local areas is located within the zone of uncertainty and the zone of radiation welfare.

Five local areas (Fig. 1) can be attributed to the zone of physiological masking based on the calculated dose rates of irradiation of molluscs.

It can be assumed that capacity by mollusc shells to accumulate Sr-90 is not subject to suppression within the given ecological zone. Increase of specific activity of radionuclide

in the mollusc shells by 2–11 times and by 2–14 time compared to its specific activities found in plants and in soil, respectively, is observed here.

Sharp reduction of specific activity of the radionuclide in mollusc shells by six and by eight times compared with the radionuclide concentration in soil and in plants, respectively, is observed within the zone of ecological masking to which seven local areas can be attributed (Fig. 2) despite the high concentration of Sr-90 both in the soil (from 370 to 5200 Bq/kg) and in plants (from 1 to 3 kBq/kg).

The obtained regularity can be explained by high sensitivity of molluscs to the effects caused by contaminants of different genesis [4,6,13]. It can be assumed that biological mechanism involved in preparing by molluscs strontium for its inclusion in the shells is also sensitive to negative effects [20]. Increased levels of ionizing radiation can be the cause of disturbance of functioning of this mechanism which leads to the reduction of concentration of the radionuclide in the shells. On the other hand, suppressive effect of Sr-90 on the capacity of molluscs to consume food can become manifested under the received dose rates. Such dependence of variation of specific activity of Sr-90 was demonstrated on four local areas within the zone of pronounced ecological effects (Fig. 3) characterized with dose rate of radiation in excess of 0.4 Gy/year.

Specific activity of the radionuclide in the mollusk shells reduced by 6–40 times compared to the radionuclide concentration in plants. Sharp increase (by 38 times) of the radionuclide concentration in plants compared to its concentration in soil is simultaneously observed.

Conclusion

Development of principles and methodologies for evaluation of conditions of biological systems with different levels of organization is the task of scientific and practical importance for successful solution of which understanding of regularities of behavior of contaminating substances in ecosystems is necessary. Regularities of migration of Sr-90 radionuclide within the “soil-plants-mollusc shells” system were revealed in the present study. It was established that molluscs of *Bradybaena Fruticicola fruticum* species are distinguished by their capacity to actively accumulate Sr-90 in their shells which can be used to characterize them as an indicator of radioactive contamination of soil and plant cover with Sr-90. Here specific activities of the radionuclide in shells vary within wide limits depending on the concentration of Sr-90 in the soil and plant cover and, correspondingly, on the dose rate of irradiation. It was determined in the present study that specific activities of Sr-90 in shells of molluscs regularly change in ecological zones identified in the conceptual model of zoning the chronic effects of ionizing radiation. It has to be noted that adaptation of bio-geochemical regularities and indicators of migration of Sr-90 in terrestrial ecosystem to the model under examination along with variative indicators previously applied within the framework of this model, such as the increase of rates of cytokinesis of protozoans *Colpoda sp*., motorial orientation of *Dugesia dorocephala* planarians, reduced mitotic activity of *Scorpena porcus* sea fishes, extinction of older age groups in the populations of *Carassius auratus gibelio*, etc. [14] is possible.

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